STATUS AND PROSPECTS OF SUPERKEKB COLLIDER AND BELLE II EXPERIMENT

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*Abstract.*High precision measurements in the quark flavor sector are essential for searching for new physics beyond the Standard model. SuperKEKB collider and Belle II detector are designed to perform such measurements. The status and prospects of the SuperKEKB and Belle II are presented in this article.

1 Introduction

Since the end of the last century, two asymmetric-energy e^+e^- B factories, the KEKB [1] collider for the Belle [2] experiment at KEK and the PEPII collider for the BaBar experiment at SLAC, have been achieving a tremendous success that lead to the confirmation of the Standard Model (SM) in the quark flavor sector. The main goal of the experiments was to measure the large mixing-induced CP violation in the B^0 system predicted by the theory of Kobayashi and Maskawa [3]. The experimental data indicated that the Kobayashi-Maskawa mechanism is indeed the dominant source of the observed CP violation in Nature. Following the experimental confirmation, M. Kobayashi and T. Maskawa were awarded the 2008 Nobel Prize for physics.

In addition to the observation of the CP violation in B meson system, a numerous of other important measurements and observations have been done by both experiments, such as measurements of all angles of the unitarity triangle; direct CP asymmetry in $B^0 \to \pi^+\pi^-$ and $K^+\pi^-$; the first observation of rare B decays, such as $B \to K^{(*)}\ell\ell$, $b \to s\gamma$ and $\tau\nu$; observation of the new type of particle, such as $X(3872)$; observation of the D^0 mixing, etc.

Most of the results are in a good agreement with the expectation from the SM, however some measurements show tension with the SM prediction. A significantly larger statistics is necessary to investigate whether these are first hints for effects of a new physics. To solve this task a next generation experiment, Belle II, operating at the high luminosity collider, SuperKEKB, is designed. In this article, the status and prospects of the SuperKEKB collider and Belle II detector are presented.

2 The Belle experiment

The Belle detector was operating on the KEKB asymmetric-energy e^+e^- collider. From 1999 to 2010, KEKB delivered an integrated luminosity of about

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1040 fb^{-1}. Most of the data were taken at the center-of-mass energy of the $\Upsilon(4S)$ resonance and contains about 772 million B meson pair events. The achieved peak luminosity is 2.1×10^{34} $\text{cm}^{-2}\text{s}^{-1}$. On June 30, 2010, the Belle experiment was stopped with the ceremonial dump of the last KEKB beam. Currently, the Belle detector is rolled out from the beam interaction point and partially disassembled.

3 Hints for a new physics

Due to the unitarity of the Cabibbo-Kobayashi-Maskawa (CKM) matrix and complexity of its elements, one can build a unitarity triangle on the complex plane from the CKM matrix elements. All sides and angles of this triangle can be measured independently, and the consistency of the obtained results is an important check of the SM and a search for a new physics. Currently, most of the CKM parameters are well measured and a room for a new physics is rather small (Fig. 1 left).

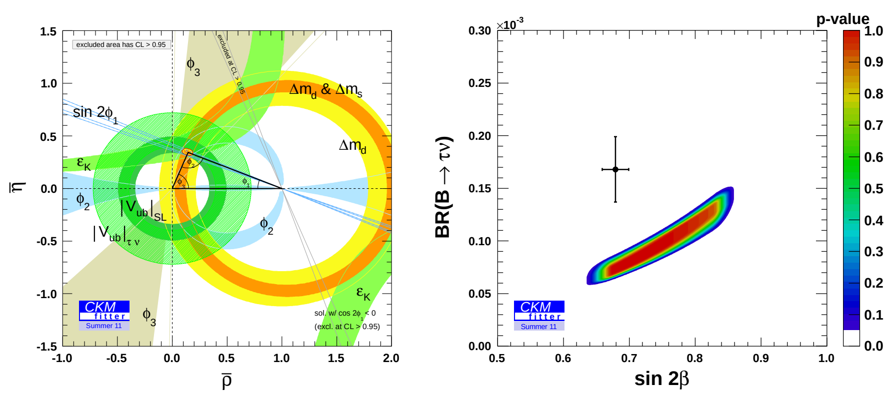

Figure 1: Unitarity triangle status from the CKMfitter group (left) and the tension between the measurements of $\mathcal{B}(B \to \tau\nu)$ and $\sin 2\phi_1$ with predictions (right).

However, there are still some small discrepancies: the indirect determination of the angle ϕ_1 is exhibiting a 2.7σ deviation from the current world average of direct measurements of $\sin 2\phi_1$ [4]. Equivalently, the $B^{\pm} \to \tau^{\pm}\nu_{\tau}$ branching fraction and the resultant $|V_{ub}|$ show a deviation of 2.8σ from the one predicted by the global fit [4], where the $\sin 2\phi_1$ value gives the most stringent constraint on the indirect measurement (Fig. 1 right).

Another place where a new physics can reveal itself is the decay of $b \to s\bar{s}s$. In the SM a time-dependent CP violation in the decay $B^0 \to \phi K_S^0$ is expected, similarly to $B^0 \to J/\psi K_S^0$, to be $\sin 2\phi_1$. However, the existence

of new particles in the penguin loop in the decay $B^0 \to \phi K^0_S$ can deviate the observed value from the expected one [5]. The current measurement gives $\Delta S \equiv \sin 2\phi_1^{B\to\phi K^0_S} - \sin 2\phi_1^{B\to J/\psi K^0_S} = 0.22 \pm 0.17$. The goal of the next experiment is to reduce the error of this measurement by the factor of 10.

A direct CP violation was measured in $B \to K\pi$ system. Since both tree and penguin processes contribute to $B^0 \to K^+\pi^-$ and $B^+ \to K^+\pi^0$ decays, sizable $\mathcal{A}_{CP}$ is expected. Moreover, $\mathcal{A}_{CP}(B^0 \to K^+\pi^-)$ and $\mathcal{A}_{CP}(B^+ \to K^+\pi^0)$ are expected to have approximately same magnitude and sign [6]. Oppositely, both $B^+ \to K^0\pi^+$ and $B^0 \to K^0\pi^0$ are almost pure penguin processes, hence no sizable asymmetries are expected in the SM.

Consistent with no asymmetry results have been obtained experimentally for the decays $B^+ \to K^0\pi^+$ and $B^0 \to K^0\pi^0$ as it was expected from the theory. However, the measured asymmetries $\mathcal{A}_{CP}(B^0 \to K^+\pi^-)$ and $\mathcal{A}_{CP}(B^+ \to K^+\pi^0)$ have different magnitudes and signs, and their difference is $\Delta\mathcal{A}_{CP} = \mathcal{A}_{CP}(B^0 \to K^+\pi^-) - \mathcal{A}_{CP}(B^+ \to K^+\pi^0) = -0.147 \pm 0.28$, which has been established with a significance of 5.3σ.

There are several theoretical models, which explain the sizable $\Delta\mathcal{A}_{CP}$ effect by the colour-suppressed tree and penguin processes. To exclude these effects and examine for a new physics, the isospin sum rule among four $\mathcal{A}_{CP}$ values can be applied [7]:

$$\mathcal{A}_{CP}^{K^+\pi^-} + \mathcal{A}_{CP}^{K^0\pi^+}\frac{\mathcal{B}(B^+ \to K^0\pi^+)\tau_{B^0}}{\mathcal{B}(B^0 \to K^+\pi^-)\tau_{B^+}} =$$

$$\mathcal{A}_{CP}^{K^+\pi^0}\frac{2\mathcal{B}(B^+ \to K^+\pi^0)\tau_{B^0}}{\mathcal{B}(B^0 \to K^+\pi^-)\tau_{B^+}} + \mathcal{A}_{CP}^{K^0\pi^0}\frac{2\mathcal{B}(B^0 \to K^0\pi^0)}{\mathcal{B}(B^0 \to K^+\pi^-)},$$

where τ_{B^0} (τ_{B^+}) is a B^0 (B^+) meson lifetime. This relation is illustrated on Fig. 2: the current status is shown on the left plot; its approximation to Belle II data is shown on the right plot. A violation of the sum rule would be an unambiguous evidence of a new physics. With all of $\mathcal{B}$ and $\mathcal{A}_{CP}$ results except for $\mathcal{A}_{CP}(B^0 \to K^0\pi^0)$, the sum rule predicts $\mathcal{A}_{CP}(B^0 \to K^0\pi^0)$ to be -0.153 ± 0.045, which is consistent with current measurement. The discrepancy can be revealed with higher precision measurements on the larger statistics of Belle II. A detailed physics program of the Belle II experiment is described in Ref. [8].

4 SuperKEKB accelerator and Belle II detector

The SuperKEKB collider is designed by upgrading the existing KEKB machine. SuperKEKB should achieve a peak luminosity about 8×10^{35} cm$^{-2}s^{-1}$. This will allow to accumulate 50 ab^{-1} around 2021-2022. This integrated luminosity corresponds approximately to 50 billion $B\bar{B}$ pair events.

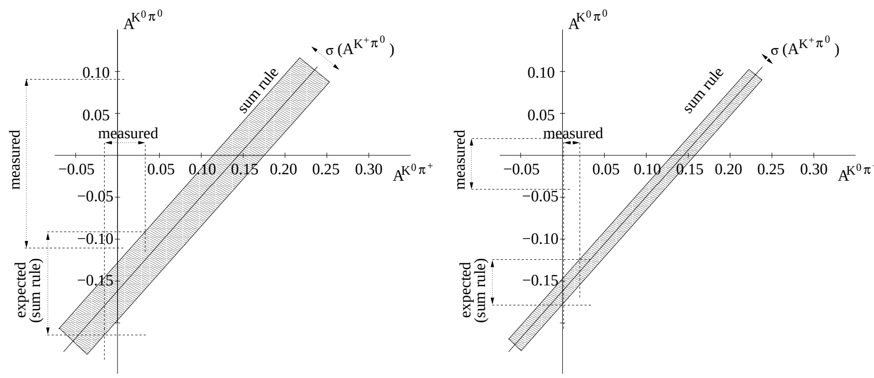

Figure 2: Illustration of the sum rule for the current experimental values (left) and the projection for SuperKEKB assuming the same central values (right).

The formula for the luminosity can be expressed as:

$$L = \frac{\gamma_{\pm}}{2er_e}\left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_{\pm}\xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right).$$

To achieve the designed luminosity goal the "nano-beam" configuration has been chosen. To increase the luminosity by the factor of 40, the accelerator parameters in the middle term of this expression will be changed: the beam current $I_{\pm}$ to be increased by the factor of 2, and the beam size β_y^* to be reduced by the factor of 20.

The Belle spectrometer will have to be upgraded to Belle II detector to accommodate much higher luminosity and to work efficiently in the conditions of much higher background level. The physics goals require also the improvements in the accuracies in all sub-detector systems. To improve the vertex resolution the silicon vertex detector will be replaced with a 2-layer DEPFET pixel detector and a 4-layer silicon strip detector. The Belle drift chamber will be replaced with a new one with smaller cell size to cope with the higher occupancy. Particle identification will be provided by a Time-of-Propagation (TOP) counter in the barrel region and a proximity focusing Cherencov ring imaging counter with aerogel radiators in the forward endcap (ARICH). Electromagnetic calorimeter will be equipped with a new electronics with wave-form sampling. The first two layers (closest to the interaction region) of the barrel part and the entire endcaps of the Belle muon system in the flux return of the magnet based on resistive plate chambers will be replaced with scintillator strips.

5 Summary

After eleven years of the successful work the Belle experiment was stopped. The Belle detector was partially disassembled and prepared for its upgrade to Belle II. The Belle II detector is designed, all sub-systems will be upgraded or replaced with new ones with better performance and stability against higher background. The aim of the new facility is to achieve a $\Upsilon(4S)$ data set equivalent to 50 ab^{-1} (about 50 billion $B\bar{B}$ pair events) around the year 2022. In the accelerator machine upgrade scheme, the increase of the luminosity will be achieved by drastically squeezing the beam size at the interaction region. A rich physics program is aimed to search for a new physics in quark flavor sector.

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